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PHILOSOPHICAL  
TRANSACTIONS.

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XIX. *An Attempt to make a Thermometer for measuring the higher Degrees of Heat, from a red Heat up to the strongest that Vessels made of Clay can support.* By Josiah Wedgwood; communicated by Sir Joseph Banks, Bart. P. R. S.

Read May 9, 1782.

A MEASURE for the higher degrees of heat, such as the common thermometers afford for the lower ones, would be an important acquisition, both to the philosopher and the practical artist. The latter must feel the want of such a measure

on many occasions; particularly when he attempts to follow, or apply to use, the curious experiments of Mr. PORT, related in his Lithogeognosia, and other modern writers upon similar subjects. When we are told, for instance, that such and such materials were changed by fire into a fine white, yellow, green, or other coloured glass: and find, that these effects do not happen, unless a particular degree of fire has fortunately been hit upon, which degree we cannot be sure of succeeding in again:—when we are disappointed, by having the result at some times an unvitrified mass, and at others an over-vitrified scoria, from a little deficiency or excess of heat:—when we see colours altered, not only in shade but in kind, and in many cases destroyed, by a small augmentation of the heat which had produced them; inasmuch, that in the gradual increase of the fire, a precise moment of time must be happily seized, in order to catch them in perfection:—and when inconveniences, similar to these, arise in operations by fire upon metals and other substances:—how much is it to be wished, that the authors had been able to convey to us a measure of the heat made use of in their valuable processes!

In a long course of experiments, for the improvement of the manufacture I am engaged in, some of my greatest difficulties and perplexities have arisen from not being able to ascertain the heat to which the experiment-pieces had been exposed. A *red*, *bright red*, and *white heat*, are indeterminate expressions; and even though the three stages were sufficiently distinct from each other, they are of too great latitude; as the brightness or luminousness of fire increases, with its force, through numerous gradations, which can neither be expressed in words, nor discriminated by the eye. Having no other resource, I have  
been

been obliged to content myself with such measures as my own kilns and the different parts of them afforded. Thus the kiln in which our glazed ware is fired furnishes three measures, the bottom being of one heat, the middle of a greater, and the top still greater: the kiln in which the biscuit ware is fired furnishes three or four others, of higher degrees of heat; and by these I have marked my registered experiments. But though these measures had been fully adequate to my own views, which they were not, it is plain, that they could not be communicated to others; that their use is confined to a particular structure of furnaces, and mode of firing; and that, upon any alteration in these, they would become useless and unintelligible, even where now they are best known. And, indeed, as this part of the operation is performed by workmen of the lowest class, we cannot depend upon any great accuracy even in one and the same furnace. It has accordingly often happened, that the pieces fired in the top of the kiln in one experiment have been made no hotter than those fired in the middle in another, and *vice versa*.

The force of fire, in its higher as well as lower stages, can no otherwise be justly ascertained than by its effects upon some known body. Its effect in changing colours has already been hinted at; and I have observed compositions of calces of iron with clay to assume, from different degrees of fire, such a number of distinct colours and shades as promised to afford useful criteria of the respective degrees.

With this idea, I prepared a quantity of such a composition, and formed it into circular pieces, about an inch in diameter, and a quarter of an inch thick. A number of these was placed in a kiln, in which the fire was gradually augmented, with as

much uniformity and regularity as possible, for near sixty hours. The pieces, taken out at equal intervals of time during this successive increase of heat, and piled in their order upon one another in a glass tube, exhibited a regular and pretty extensive series of colours; from a flesh-colour to a deep brownish-red, from thence to a chocolate, and so on to nearly black, with all the intermediate tints between these colours. A back being fixed to the tube, like the scale of a thermometer, and the numbers of the pieces marked upon it respectively opposite to them, it is obvious, that these numbers may be considered as so many thermometric divisions or degrees; and that, if another piece of the same composition be fired in any other kiln or furnace, not exceeding the utmost heat of the first, it will acquire a colour corresponding to some of the pieces in the tube, and thus point out the degree of heat which that piece, and consequently such other matters as were in the fire along with it, have undergone.

It must however be confessed, that, for general use, a thermometer on this principle is liable to objection, as ideas of colours are not perfectly communicable by words; nor are all eyes, or all lights, equally adapted for distinguishing them, especially the shades which approach near to one another; and the effects of phlogistic vapours, in altering the colour, may not in all cases be easily guarded against.

In considering this subject attentively, another property of argillaceous bodies occurred to me; a property which obtains, in a greater or less degree, in every kind of them that has come under my examination, so that it may be deemed a distinguishing character of this order of earths: I mean, the *diminution of their bulk by fire*; I have the satisfaction to find, in a course

of experiments lately made with this view, that it is a more accurate and extensive measure of heat than the different shades of colour.

I have found, that this diminution begins to take place in a low red-heat; and that it proceeds regularly, as the heat increases, till the clay becomes vitrified, and consequently to the utmost degree that crucibles, or other vessels made of this material, can support. The total contraction of some good clays which I have examined, in the strongest of my own fires, is considerably more than one-fourth part in every dimension.

If, therefore, we can procure at all times a clay sufficiently apyrous or unvitrescible, and always of the same quality in regard to contraction by heat; and if we can find means of measuring this contraction with ease and minute accuracy, I flatter myself, that we shall be furnished with a measure of fire sufficient for every purpose of experiment or business.

We have, in different parts of England, immense beds of clay; each of which, at equal depths, is pretty uniform in quality throughout its whole extent. Of all the sorts I have hitherto tried, some of the purest Cornish porcelain clays seem the best adapted, both for supporting the intensity, and measuring the degrees, of fire.

For preparing and applying this material to thermometric purposes the following method is proposed.

The clay is first to be washed over, and, whilst in a dilute state, passed through a fine lawn. Let it then be made dry, and put up in boxes\*,

\* While the clay is thus kept dry in boxes, as well as while it continues in its natural bed, it is secure from alterations in quality, which clays in general are subject to undergo, when exposed, for a long course of years, to the joint actions of air and moisture.—In the lawns I made use of, the interstices were each less than the 100,000 part of an inch.

The dry clay is to be softened, for use, with about two-fifths of its weight of water ; and formed into small pieces, in little moulds of metal, six-tenths of an inch in breadth, with the sides pretty exactly parallel, this being the dimension intended to be measured, about four-tenths of an inch deep, and one inch long. To make the clay deliver easily, it will be necessary to oil the mould, and make it warm.

These pieces, when perfectly dry, are put into another iron mould or gage, consisting only of a bottom, with two sides, five-tenths of an inch deep ; to the dimensions of which sides the breadth of the pieces is to be pared down.

For measuring the diminution which they are to suffer from the action of fire, another gage is made, of two pieces of brass, twenty-four inches long, with the sides exactly straight, divided into inches and tenths, fixed five tenths of an inch asunder at one end, and three-tenths at the other, upon a brass plate ; so that one of the thermometric pieces, when pared down in the iron gage, will just fit to the wider end. Let us suppose this piece to have diminished in the fire one-fifth of its bulk, it will then pass on to half the length of the gage ; if diminished two-fifths, it will go on to the narrowest end ; and in any intermediate degree of contraction, if the piece be slid along till it rests against the converging sides, the degree at which it stops will be the measure of its contraction, and consequently of the degree of heat it has undergone.

These are the outlines of what appears to me necessary for the making and using of this thermometer ; and it is hoped, that the whole process will be found sufficiently simple, and easy of execution. It may, nevertheless, be proper to take notice of a few minuter circumstances, and to mention  
some

some observations which occurred in the progress of the inquiry.

I. There ought to be a certainty of the clay being easily, and at all times, procurable in sufficient quantity, and on moderate terms. That this is the case with the clay here made choice of, will be evident to every one acquainted with the natural history of Cornwall, where there are beds of this clay, inexhaustible, and in too many hands to be monopolized. If this should not prove satisfactory, the author offers to this illustrious Society, and will think himself honoured by their acceptance of, a sufficient space in a bed of this clay to supply the world with thermometer-pieces for numerous ages; and he does not apprehend, that any greater inconveniences can arise to foreign artists or philosophers, from their being supplied with clay for these thermometers from this spot only, than what we now feel from being supplied with mercury for the common thermometers from the Spanish or Hungarian mines.

II. We ought to be assured also, that all the clay made use of for these thermometers is perfectly similar. For this purpose, it will be best to dig it out of the earth in considerable quantity at once, an extent of some square feet or yards in area, and to the depth of six or seven yards or more from the surface, and to mix the whole thoroughly together, previous to the further preparation already mentioned. When the first quantity is exhausted, another perpendicular column may be dug from the same bed, close to the first, to the same depth, and prepared in the same manner; by which means we may be assured of its similarity with the former parcel, and that it will diminish equally in the fire.



III. This clay, dried by the summer heat, or in a moderately warm room, or with more heat before a fire, has not been observed to differ in *degree* of dryness. After being so dried, it loses about a hundredth part of its weight in the heat of boiling water, about as much more in that of melted lead, and from thence to a red-heat ten parts, in all  $\frac{1}{100}$ . Each of these heats soon expels from the clay its determinate quantity of matter, chiefly air; after which, the same heat, though continued for many hours, has no further effect. I had some hopes, that the graduation of the common thermometer might be continued, upon this principle, up to the red-heat at which the shrinking of the clay commences, so as to connect the two thermometers together by one series of numbers; but the loss of weight appears not to be sufficiently uniform or proportional to the degree of heat to answer that purpose; for it was found to go on quicker, and bladders tied to the mouths of the vessels in which the pieces were heated, became more rapidly distended, at the commencement of redness than at any other time. From low red-heat to a strong one, such as copper melts in, the loss of weight was only about two parts in a hundred; though the difference between these two heats appears to be much greater than what the same loss corresponds to in the lower stages. After this period, the decrease of weight intirely ceased.

The vapours expelled from the clay, caught separately in the different degrees of heat, seemed, from the few trials made with them, to consist of common air mixed with fixt air. They all precipitated lime-water; that which was first extricated, exceeding weakly; the others more and more considerably; but the last not near so strongly as the air expelled from lime-stone in burning. None of them were inflammable.

IV.

IV. The thermometric pieces may be formed much more expeditiously than in the single mould, by means of an instrument used for similar purposes by the potters. It consists of a cylindrical iron vessel, with holes, in the bottom, of the form and dimensions required. The soft clay, put in the vessel, is forced by a press down through these apertures, in long rods, which may be cut while moist, or broken when dry, into pieces of convenient lengths. It was hoped, that this method would of itself have been sufficient, without the addition of the paring gage, making proper allowance, in the size of the holes, for the shrinking of the clay in drying. But it was found, that a variety of little accidents might happen to alter the shape and dimensions of the pieces, in a sensible degree, while in their soft state; so that it will be always safest to have recourse to the paring gage, for ascertaining and adjusting their breadth when perfectly dry, this being the period at which the pieces are exactly alike with regard to their future diminishing; so that if they are now reduced to the same breadth, we may be sure that they will suffer equal contractions from equal degrees of heat afterwards, whether they have been made in a mould, or by a press, or in any other way; neither is any variation in the length or thickness of these pieces of the least consequence, provided one of the dimensions, that by which they are afterwards to be measured, is made accurate to the gage.

V. It will be proper to bake the pieces, when dry, with a low red-heat, in order to give them some firmness or hardness, that they may, if necessary, be able to bear package and carriage; but more especially to prepare them for being put into an immediate heat, along with the matters they are to serve as measures to, without bursting or flying, as unburnt clay would

do. We need not be solicitous about the precise degree of heat employed in this baking, provided only that it does not exceed the lowest degree which we shall want to measure in practice; for a piece that has suffered any inferior degrees of heat, answers as well for measuring higher ones as a piece which has never been exposed to fire at all. In this part of the preparation of the pieces, it may be proper to inform the operator of a circumstance, which, though otherwise immaterial, might at first disconcert him: if the heat is not in all of them exactly equal, he will probably find, that while some have begun to shrink, others are rather enlarged in their bulk; for they all swell a little just on the approach of redness. As this is the period of the most rapid produce of air, the extension may perhaps be owing to the air having at this moment become elastic to such a degree, as to force the particles of the clay a little asunder before it obtains its own enlargement.

VI. Each division of the scale, though so large as a tenth of an inch, answers to  $\frac{1}{10}$ th part of the breadth of the little piece of clay. We might go to much greater nicety, either by making the divisions smaller, or the scale longer; but it is not apprehended, that any thing of this kind will be found necessary: and, indeed, in proceeding much further in either way, we may possibly meet with inconveniences sufficient to counterbalance the apparent additional accuracy of measurement.

VII. The divisions of this scale, like those of the common thermometers, are unavoidably arbitrary; but the method here proposed appears sufficiently commodious and easy of execution, the divisions being adjusted by measures everywhere known, and at all times obtainable: for however the inches used in different countries may differ in length, this cannot affect

affect the accuracy of the scale, provided that the proportions between the wider and narrower end of the gage are exactly as five-tenths of those inches to three-tenths, and the length 240 of the same tenths; and that the pieces in their perfectly dry state, before firing, fit precisely to the wider end. When one gage is accurately adjusted to these proportional measures, two pieces of brass should be made, one fitting exactly into one end, and the other into the other: these will serve as standards for the ready adjustment of other gages to the dimensions of the original.

By this simple method we may be assured, that thermometers on this principle, though made by different persons, and in different countries, will all be equally affected by equal degrees of heat, and all speak the same language: the utility of this last circumstance is now too well known to need being insisted on.

VIII. If a scale two feet in length should be reckoned inconvenient, it may be divided into two, of one foot each, by having three pieces of brass fixed upon the same plate; the first and second, five-tenths of an inch apart at one end, and four-tenths at the other; the second and third, four-tenths at one end, and three-tenths at the other; so that the first reaches to the 120th division, and the second from thence to the 240th.

IX. As this thermometer, like all others, can express only the heat felt by itself, the operator must be careful to expose the pieces to an equal action of the fire with the body whose heat he wants to measure by them. In kilns, ovens, reverberatories, under a muffle, and wherever the heat is pretty steady and uniform, the means of doing this are too

obvious to need being mentioned. But in a naked fire, where the heat is necessarily more fluctuating, and unequal in different parts of the fuel, some precaution will be required.

The thermometer-piece may generally be put into the crucible, along with the subject-matter of the experiment. But where the matter is of such a kind as to melt and stick to it, the piece may be previously inclosed in a little case made of crucible clay. The smallness of the pieces will admit of this being done without inconvenience, at least in any but the smallest crucibles, as the pieces themselves may be diminished to any size that may be found proper, provided only that one of the dimensions, five-tenths of an inch, be preserved, as mentioned in *Obs.* 4.

For the very smallest sort of crucibles, the case may be put in close to the crucible, so as to form as it were an addition to its bulk on the outside. If it be asked, why the case is not always thus put in by the side of the crucible? it is answered, that in judging of the heat of *large* crucibles from a thermometer-piece placed on the outside of them, we may sometimes be deceived, as the piece in its little case has been found to heat sooner than the matter in the larger vessel; but in *small* ones, as the crucible and case are nearly alike in bulk, there is little danger of error from this cause.

X. These thermometer-pieces possess some singular properties, which we could not have expected to find united in any substance whatever, and which peculiarly fit them for the purposes they are here applied to.

1. When baked by only moderate degrees of fire, though they are, like other clays, of a porous texture, and imbibe

water; yet, when saturated with the water, their bulk continues exactly the same as in a dry state.

2. By very strong fire, they are changed to a porcelain or semi-vitreous texture; nevertheless, their contraction, on further augmentations of the heat, proceeds regularly as before, up to the highest degree of fire that I have been able to produce.

3. They bear sudden alternatives of heat and cold; may be dropped at once into intense fire, and, when they have received its heat, may be plunged as suddenly into cold water, without the least injury from either.

4. Even while saturated with water in their porous state, they may be thrown immediately into a white heat, without bursting or suffering any injury.

5. Sudden cooling, which alters both the bulk and texture of most bodies, does not at all affect these, at least not in any quality subservient to their thermometric uses.

6. Nor are they affected by long *continuance* in, but solely by, the *degree* of heat they are exposed to. In three minutes or less, they are perfectly penetrated by the heat which acts upon them, so as to receive the full contraction which that degree of heat is capable of producing equally with those which had undergone its action during a gradual increase of its force for many hours. Strong degrees of heat are communicated to them with more celerity than weak ones: perhaps the heat may be more readily transmitted, in proportion as the texture becomes more compact.

These facts have been ascertained by many experiments, the particulars of which are omitted, because they would swell this paper much beyond the bulk intended.

XI. The use and accuracy of this thermometer for measuring, *after an operation*, the degree of heat which the matter has undergone, will be apparent. The foregoing properties afford means of measuring it also, easily and expeditiously, *during the operation*, so that we may know when the fire is increased to any degree previously determined upon. The piece may be taken out of the fire in any period of the process, and dropped immediately into water, so as to be fit for measuring by the gage in a few seconds of time. At the same instant, another piece may be introduced into the place of the former, to be taken out and measured in its turn; and thus alternately, till the desired degree of heat is obtained. But as the cold piece will be two or three minutes in receiving the full heat, and corresponding contraction; to avoid this loss of time, it may be proper, on some occasions, to have two or more pieces, according to convenience, put in together at first, that they may be successively cooled in water, and the degrees of heat examined at shorter intervals. It will be unnecessary to say any thing further upon precautions or procedures which the very idea of a thermometer must suggest, and in which it is not apprehended that any difficulty can occur, which every experimenter will not readily find means to obviate.

XII. It now only remains, that the language of this new thermometer be understood, and that it may be known what the heats meant by its degrees really are. For this purpose a great number of experiments has been made, from which the following results are selected.

The scale commences at a red-heat, fully visible in daylight; and the greatest heat that I have hitherto obtained in my experiments is  $160^{\circ}$ . This degree I have produced in an air-furnace about eight inches square.

Mr. ALCHORNE has been so obliging as to try the necessary experiments with the pure metals at the Tower, to ascertain at what degrees of this thermometer they go into fusion; and it appears, that Swedish copper melts at 27, silver at 28, and gold at 32.

Brass is in fusion at 21. Nevertheless, in the brass and copper foundries, the workmen carry their fires to 140° and upwards: for what purpose they so far exceed the melting heat, or whether so great an additional heat be really necessary, I have not learnt.

The welding heat of iron is from 90 to 95; and the greatest heat that could be produced in a common smith's forge 125.

Cast iron was found to melt at 130°, both in a crucible in my own furnace, and at the foundry; but could not be brought into fusion in the smith's forge, though that heat is only 5° lower. The heat by which iron is run down among the fuel for casting is 150°.

As the welding state of iron is a softening or beginning fusion of the surface, it has been generally thought that cast iron would melt with much less heat than what is necessary for producing this effect upon the forged; whereas, on the contrary, cast iron appears to require, for its fusion, a heat exceeding the welding heat 35 or 40°, which is much more than the heat of melted copper exceeds the lowest visible redness.

Thus we find, that though the heat for melting copper is by some called a white heat, it is only 27° of this thermometer. The welding heat of iron, or 90°, is likewise a white heat; even 130°, at which cast iron is in fusion, is no more than a white heat; and so on to 160° and upwards is all a white heat still. This shews abundantly how vague such a denomination must be, and how inadequate to the purpose of giving us any clear ideas



ideas of the extent of what we have been accustomed to consider as one of the three divisions of heat in ignited bodies.

A Hessian crucible, in the iron foundry, *viz.* about  $150^{\circ}$ , melted into a slag-like substance. Soft iron nails, in a Hessian crucible in my own furnace, melted into one mass with the bottom of the crucible, at  $154^{\circ}$ : the part of the crucible above the iron was little injured.

The *fonding* heat of the glass furnaces I examined, or that by which the perfect vitrification of the materials is produced, was at one of them  $114^{\circ}$  for flint-glass, and  $124^{\circ}$  for plate-glass; at another it was only  $70^{\circ}$  for the former, which shews the inequality of heat, perhaps unknown to the workmen themselves, made use of for the same purpose. After complete vitrification, the heat is abated for some hours to 28 or  $29^{\circ}$ , which is called the *settling* heat; and this heat is sufficient for keeping the glass in fusion. The fire is afterwards increased, for working the glass, to what is called the *working* heat; and this I found, in plate-glass, to be  $57^{\circ}$ .

Delft ware is fired by a heat of 40 or  $41^{\circ}$ ; cream-coloured, or Queen's ware, by  $86^{\circ}$ ; and stone ware, called by the French *pots de grès*, by  $102^{\circ}$ : by this strong heat, it is changed to a true porcelain texture. The thermometer-pieces begin to acquire a porcelain texture about  $110^{\circ}$ .

The above degrees of heat were ascertained by thermometer-pieces fired along with the ware in the respective kilns. But this thermometer affords means of doing much more, and going further in these measures than I could at first even have expected; it will enable us to ascertain the heats by which many of the porcelains and earthen wares of distant nations and different ages have been fired: for as burnt clay, and compositions in which clay is a prevailing ingredient, suffer no  
diminution

diminution of their bulk by being re-passed through degrees of heat which they have already undergone, but are diminished by any additional heat (according to *Obs. V.*), if a fragment of them be made to fit into any part of the gage, and then fired along with a thermometer-piece till it begins to diminish, the degree at which this happens points out the heat by which it had been fired before. Of several pieces of ancient Roman and Etruscan wares, which I have examined, none appear to have undergone a greater heat than  $32^{\circ}$ , and none less than  $20^{\circ}$ ; for they all began to diminish at those or the intermediate degrees.

By means of this thermometer some interesting properties of natural bodies may likewise be discovered or more accurately determined, and the genus of the bodies ascertained. Jasper, for instance, is found to diminish in the fire, like an artificial mixture of clay and siliceous matter; granite, on the contrary, has its bulk enlarged by fire, whilst flint and quartzose stones are neither enlarged nor diminished. These experiments were made in fires between  $70$  and  $80^{\circ}$  of this thermometer. A sufficient number of facts like these, compared with each other, and with the properties of such natural or artificial bodies as we wish to find out the composition of, may lead to various discoveries, of which I have already found some promising appearances; but many more experiments are wanting to enable me to speak with that certainty and precision on these subjects which they appear to deserve.

A piece of an Etruscan vase melted completely at  $33^{\circ}$ ; pieces of some other vases and Roman ware about  $36^{\circ}$ ; Worcester china vitrified at  $94^{\circ}$ ; Mr. SPRIMONT's Chelsea china at  $105^{\circ}$ ; the Derby at  $112^{\circ}$ ; and Bow at  $121^{\circ}$ ; but Bristol china shewed no appearance of vitrification at  $135^{\circ}$ . The common sort

of Chinese porcelain does not perfectly vitrify by any fire I could produce; but began to soften about  $120^{\circ}$ , and at  $156^{\circ}$  became so soft as to sink down, and apply itself close upon a very irregular surface underneath. The true stone Nankeen, by this strong heat, does not soften in the least; nor does it even acquire a porcelain texture, the unglazed parts continuing in such a state as to imbibe water and stick to the tongue. The Dresden porcelain is more refractory than the common Chinese, but not equally so with the stone Nankeen. The cream-coloured or Queen's ware bears the same heat as the Dresden, and the body is as little affected by this intense degree of fire.

Mr. PORT says, that to melt a mixture of chalk and clay in certain proportions, which proportions appear from his tables to be equal parts, is "among the master-pieces of art." This mixture melts into a perfect glass at  $123^{\circ}$  degrees of this thermometer.

The whole of Mr. PORT's or any other experiments may, by repeating and accompanying them with these thermometric pieces, have their respective degrees of heat ascertained, and thereby be rendered more intelligible, and useful, to the reader, the experimenter, and the working artist.

I flatter myself that a field is thus opened for a new kind of thermometrical inquiries; and that we shall obtain clearer ideas with regard to the differences of the degrees of strong fire, and their corresponding effects upon natural and artificial bodies; those degrees being now rendered accurately measurable, and comparable with each other, equally with the lower degrees of heat which are the province of the common mercurial thermometer.

## A P P E N D I X.

### ANALYSIS OF THE CLAY OF WHICH THE THERMOMETRIC PIECES ARE FORMED.

THIS clay makes no effervescence with acids. Diluted nitrous and marine acids being boiled upon it, and afterwards saturated with fixed alkali, no precipitation or turbidness appeared. It therefore contains no calcareous earth, as that earth would have been dissolved by the acids, and precipitated from them by the alkali.

Calcined with powdered charcoal, it contracted no sulphureous smell, and the acids had no more action upon it than before. It therefore contains no gypseous matter, or combination of calcareous earth with vitriolic acid; as that acid would have formed sulphur with the inflammable principle of the charcoal, and left the calcareous earth pure, or in a state of solubility by acids.

Some of the clay was calcined with an equal weight of salt of tartar, which, for the greater certainty in regard to its purity, had been run *per deliquium*, and afterwards evaporated to dryness. The calcined mixture was boiled in water, the filtered liquor slowly evaporated, and suffered to cool at intervals. No crystallization was formed: the dry salt appeared merely alkaline as at first, and deliquiated in the air; a further proof that this clay contains no gypseous matter; for the vitriolic acid would have been absorbed by the alkali, and formed vitriolated tartar, a salt which neither liquefies in the air,

nor dissolves easily in water, and which therefore would have crystallized long before the alkali became dry, or remained after its deliquiation.

A twentieth part of gypsum, ground with clay, was very distinguishable by both the foregoing processes; producing a sulphureous smell, and calcareous earth by calcination with charcoal powder; and crystals of vitriolated tartar by calcination with the same alkaline salt.

To separate the pure argillaceous part, or that matter which in all clays forms alum with the vitriolic acid, 240 grains of this clay were thoroughly moistened with oil of vitriol, boiled to dryness, and at last made nearly red-hot. The mixture was then boiled in water; the earth which remained undissolved was treated again in the same manner with vitriolic acid, and this operation repeated five or six times. The clay was diminished in the first operation about 70 grains; but less and less in the succeeding ones, and in the last scarcely two grains. The filtered liquors yielded crystals of true alum; but its quantity was not examined, as the produce of alum from aluminous earth is already sufficiently known, and the quantity of aluminous earth itself, or its proportion to the indissoluble earth, was here the object. From the 240 grains of clay there remained in one experiment 98, and in another 95 grains of indissoluble earth; so that five parts of this clay consist of three parts of pure argillaceous or alum earth, and two parts of an earth of a different kind.

With respect to the nature of this last earth, it is easier to determine negatively what it is not, than positively what it is; but ascertaining the former will be a great step towards the discovery of the latter.

That it is not calcareous, gypseous, or argillaceous, is manifest from the experiments.—It is not jasper; as this consists, in great part, of argillaceous earth, which would have been extracted by the vitriolic acid.—It is not fluor; as this, by the same acid, would have been decomposed, its own acid expelled, and a gypseous earth left.—It is not of the micaceous kind; as the peculiar aspect of these earths would readily betray them to the eye.—It is not granite; for strong fire, which granite melts in, has no effect upon this.

Nor is there any known kind of earth to which it is in any degree similar, except those of the siliceous order; and with these it perfectly agrees in all the properties, I am acquainted with, that they possess in a state of powder.

It does not vitrify or soften with pure clay, in the strongest fire I have been able to produce. Nor is it disposed to melt with the matter of Hessian crucibles; for a little of it rubbed on the inside of a crucible, and urged with strong fire, continued white, powdery, and unaltered. Thirty grains of this earth were mixed with an equal weight of dry fossil alkali, and the same quantity of a fine white quartz sand was mixed with the same proportion of the same alkali: the two mixtures were put into two small crucibles, which were surrounded with sand in a larger one, that both might be exposed to an equal heat. They both began to melt at the same time; and at about 80° of the thermometer they had formed perfect transparent glasses.

Though these properties may not, perhaps, be thought sufficient of themselves, for determining with certainty that this substance is of the siliceous kind; yet, when joined to the negative proofs, of its not belonging to any other known order  
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of earthy bodies, they afford the fullest evidence which the nature of the subject can admit of, that the indissoluble part of this clay is truly filiceous; and consequently that the clay consists of two parts of pure filiceous earth, to three parts of pure argillaceous or aluminous earth.

